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INFLUENCE OF TARGET STRENGTH ON HYPERVELOCITY CRATER FORMATION IN ALUMINUM

J. H. Kineke, Jr.
L. G. Richards

RDT & E Project No. 1M010501A009

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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MEMORANDUM REPORT NO. 1480

JHKineke,Jr/LGRichards/mec
Aberdeen Proving Ground, Md.
June 1963

INFLUENCE OF TARGET STRENGTH ON HYPERVELOCITY
CRATER FORMATION IN ALUMINUM

ABSTRACT

Aluminum projectiles with velocity of 9.7 km/sec and beryllium projectiles with velocity of 15.5 km/sec have been used to produce craters in aluminum and aluminum alloy targets. Results indicate that the influence of the mechanical strength of the target in determining final crater dimensions extends unimpaired for impact velocities up to 15.5 km/sec. These data have also been used to verify the linear dependence of crater volume on projectile energy.

INTRODUCTION

Earlier Hypervelocity Impact Symposia have seen the presentation of a number of papers dealing with observations of crater dimensions in semi-infinite metallic targets. The linear dependence of crater volume on projectile energy have been fairly well established, for impact velocities up to 6 km/sec. However, consideration of the effect of target strength has been limited and at best oblique. The purpose of the investigation reported in this paper is two-fold: 1. To determine whether or not crater dimensions are significantly influenced by target mechanical properties at impact velocities up to 15.5 km/sec; and 2. To examine the dependence of crater volume on projectile energy at impact velocities up to 9.7 km/sec.

TARGET STRENGTH

Experimental Observations

Previous experimental investigations of the influence of target strength on the cratering process fall into two categories: studies of energy absorbing mechanisms. and empirical correlations of crater dimensions with various mechanical properties. Glass and Pond [1a][2a] have studied the mechanism of energy distribution in the target after impact by means of static stress-strain relationships. Empirical correlations have been made of crater data with several mechanical strength properties, including shear strength [3], ultimate tensile strength [3], Brinell hardness [1b], and yield strength [4a]. Several groups [1c,4b] have also made empirical correlations of crater dimensions with ambient target temperature, with the implication that by varying the temperature some pertinent mechanical strength property of the target would also be varied and thus its influence noted. In general, the temperature correlations, as well as the strength correlations, have not pinpointed which strength properties are important, perhaps because the strength-temperature relations were not measured on the particular target materials, over the temperature range used in the impact tests. In most instances, strength parameters are not sufficiently independent to establish a preference, using handbook values. However, the empirical correlations have demonstrated, at least

qualitatively, that final crater dimensions do indeed depend on the mechanical and metallurgical properties of the target, for impact velocities up to 6 km/sec. At sufficiently high impact velocities, and hence high impact pressures, it is generally agreed that only the high pressure properties of materials, the density and the compressibility, are important in determining material behavior early in the crater formation process. Efforts to compute the entire crater formation process by a hydrodynamic approximation (4c) require neglecting low pressure mechanical properties entirely. The investigation reported in this paper is designed to determine whether: 1. available projectile velocities have achieved a regime where density and compressibility predominate and mechanical strength effects are negligible; or 2. approach to the lower limit of such a regime is indicated.

These questions have been examined by considering the ratio of crater volume in a mechanically strong aluminum alloy, to crater volume in a relatively weak material, commercially pure aluminum. While the low pressure properties differ markedly, the high pressure properties are essentially identical, as indicated by Hugoniot data in Figure 1, where no difference is apparent between pure aluminum and an aluminum alloy similar to that used in this experiment. If, then, the high pressure properties predominate, the ratio of crater volumes would be expected to be near unity. If low pressure properties predominate, the ratio should be less than one, and if the role of the high pressure properties is increasing with increasing impact velocity, the ratio should be observed to increase.

As a basis for comparison with lower velocity data, 1100 aluminum and 2014 aluminum alloy were chosen as target materials, since, at the Fifth Hypervelocity Symposium, Halperson and Atkins (4d) of NRL reported crater data for aluminum projectiles into these materials. In order to assure quasi-infinite targets, diameters of 25 cm and thicknesses of 20 cm were used. Impact surfaces were machined in each target, Brinell hardnesses were measured, and ambient target temperatures at the time of firing were recorded, all as controls on the reproducibility of the targets used.

Two sets of experiments were conducted, one with aluminum projectiles at 9.7 ± 0.1 km/sec, and the second with beryllium projectiles at 15.5 ± 0.4 km/sec. In both cases, velocities were determined with multiple flash

radiographs. The 1100 aluminum projectile was fired from a BRL Inhibited-Jet Charge, which was described in detail by Kronman in a paper at the Sixth Hypervelocity Impact Symposium [2b,11]. The projectile is somewhat elongated in shape, having a length-to-diameter ratio between 2.5 and 3, as shown in Figure 2. The beryllium projectile is a BRL Jet-Pellet, similar to that described at the Fifth Hypervelocity Impact Symposium [4e]. Flash radiographs indicate that the pellet is not an integral unit, but rather a cluster of tightly packed particles with a length-to-diameter ratio of five to ten.

A tabulation of crater data appears in Table I, together with a list of target parameters. Typical craters in each of the materials are shown in Figure 2. For a given material there was little difference in appearance of craters at the two impact velocities, although craters made by beryllium projectiles could not be sectioned because of safety considerations. At both velocities craters in 1100 aluminum were smooth-walled, with large lips, i.e., in general gave the appearance of typical hypervelocity craters in ductile metals. In contrast, the craters in the 2014 alloy were irregular in shape, with appreciable lip spall, because 2014 alloy is less ductile than 1100 aluminum. Because of this semibrittle behavior there is more scatter in the depth and diameter data, taken individually, than in the crater volume data, which represents an averaging over the entire crater. For this reason, volume was chosen as the basis for comparison.

An insight into the relative importance of target strength in determining final crater volume can be gained . ı Figure 3. The ratio of crater volume in the high strength material to that in the low strength material is plotted as a function of the impact velocity. The solid line represents the low velocity NRL results. The plotted ratios indicate no tendency to increase with increasing impact velocity, as would be expected if the effect of target strength on the crater formation process were becoming relatively less important.

Conclusions

1a. For impact velocities up to 15.5 km/sec, the mechanical strength of the target is a significant property in determining final crater dimensions.

1b. For impact velocities up to 15.5 km/sec, there is no indicated tendency that the influence of mechanical strength of the target on final crater dimensions is decreasing.

ENERGY DEPENDENCE

Experimental Observations

In order to examine the energy dependence of crater volume, it is necessary to know not only the projectile velocity, but also the projectile mass. The mass of the 9.7 km/sec aluminum projectile described earlier has been determined to be 3.7 ± 0.3 grams (2b). The mass of the 15.5 km/sec beryllium projectile is about 0.2 gram, but somewhat uncertain, so beryllium data have not been used. The fact that the beryllium mass has not been satisfactorily determined does not in any way affect the conclusions of the previous section, since only ratios of crater volumes were used and the beryllium mass is reproducible within about seven percent, as evidenced by the reproducibility of the crater data. A plot of crater volume per unit projectile mass as a function of the impact velocity is shown in Figure 4, for both 1100 aluminum and 2014 aluminum alloy. Also plotted, as solid lines up to 6 km/sec, with extrapolations to higher velocities, are the NRL results. The recently acquired high velocity data are in agreement with the extrapolated lower velocity curves.

Conclusion

2. The oft-stated conclusion that crater volume is proportional to projectile energy is further supported for impact velocities up to 9.5 km/sec.

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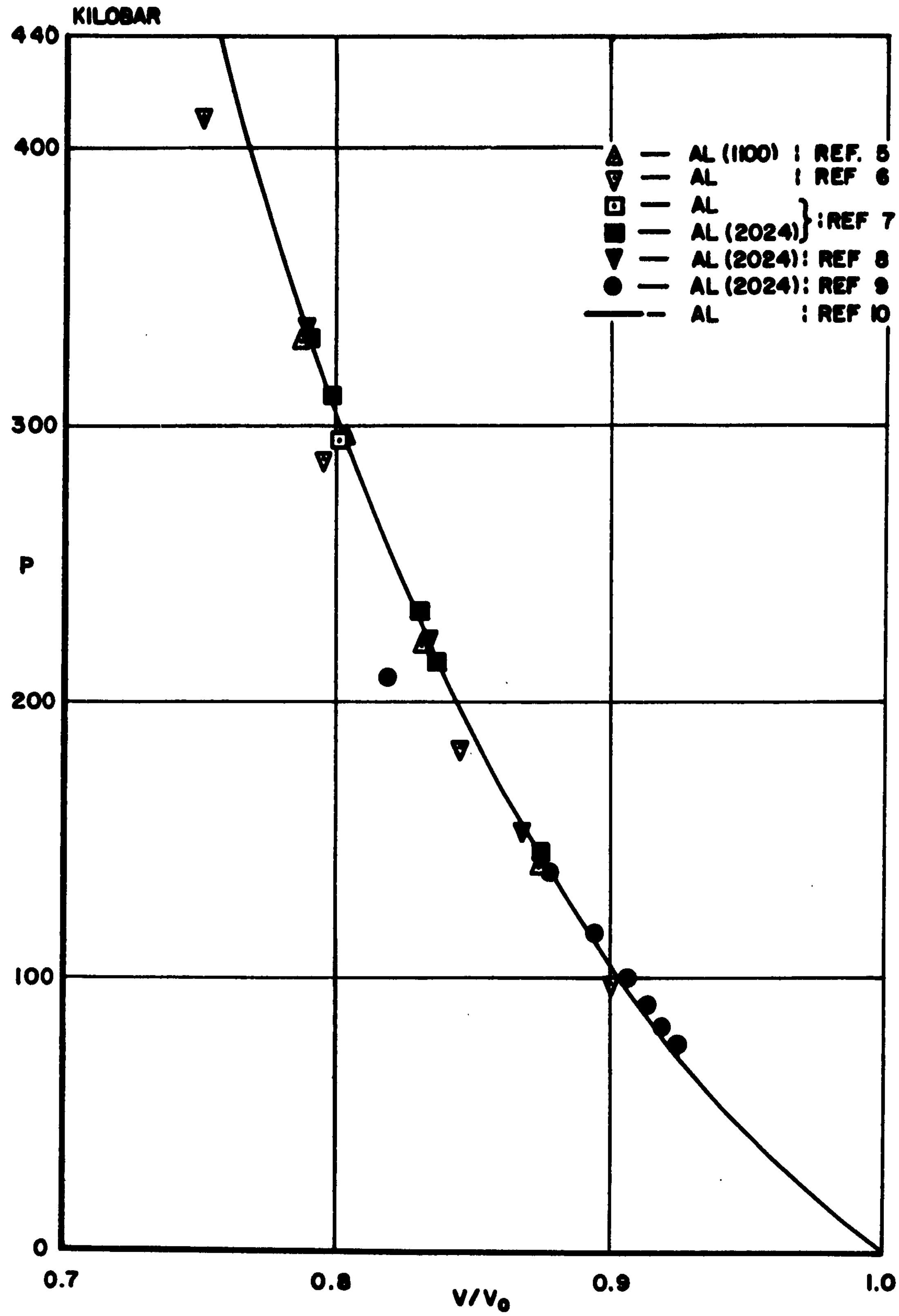
TABLE I

Target Material	BHN	v_p km/sec	Temp ^oC	P_c cm	σ_m cm	Dc_c cm	σ_m cm	V_c cm^3	σ_m cm^3
Al-1100	24-25	9.7	5	5.90	0.17	8.44	0.13	230	18
Al-2014	137	9.7	-4	5.00	0.07	5.60	0.17	92.5	4.0
Al-1100	26-27	15.5	10	4.24	0.31	4.02	0.14	35.6	2.5
Al-2014	146-156	15.5	10	2.97	0.67	3.36	0.37	9.2	0.6



KILOBAR
440
400
300
200
100
0
P
0.7
0.8
0.9
1.0
V/V₀
AL (1100) : REF. 5
AL : REF 6
AL
AL (2024) : REF 7
AL (2024) : REF 8
AL (2024) : REF 9
AL : REF 10

FIG. 1

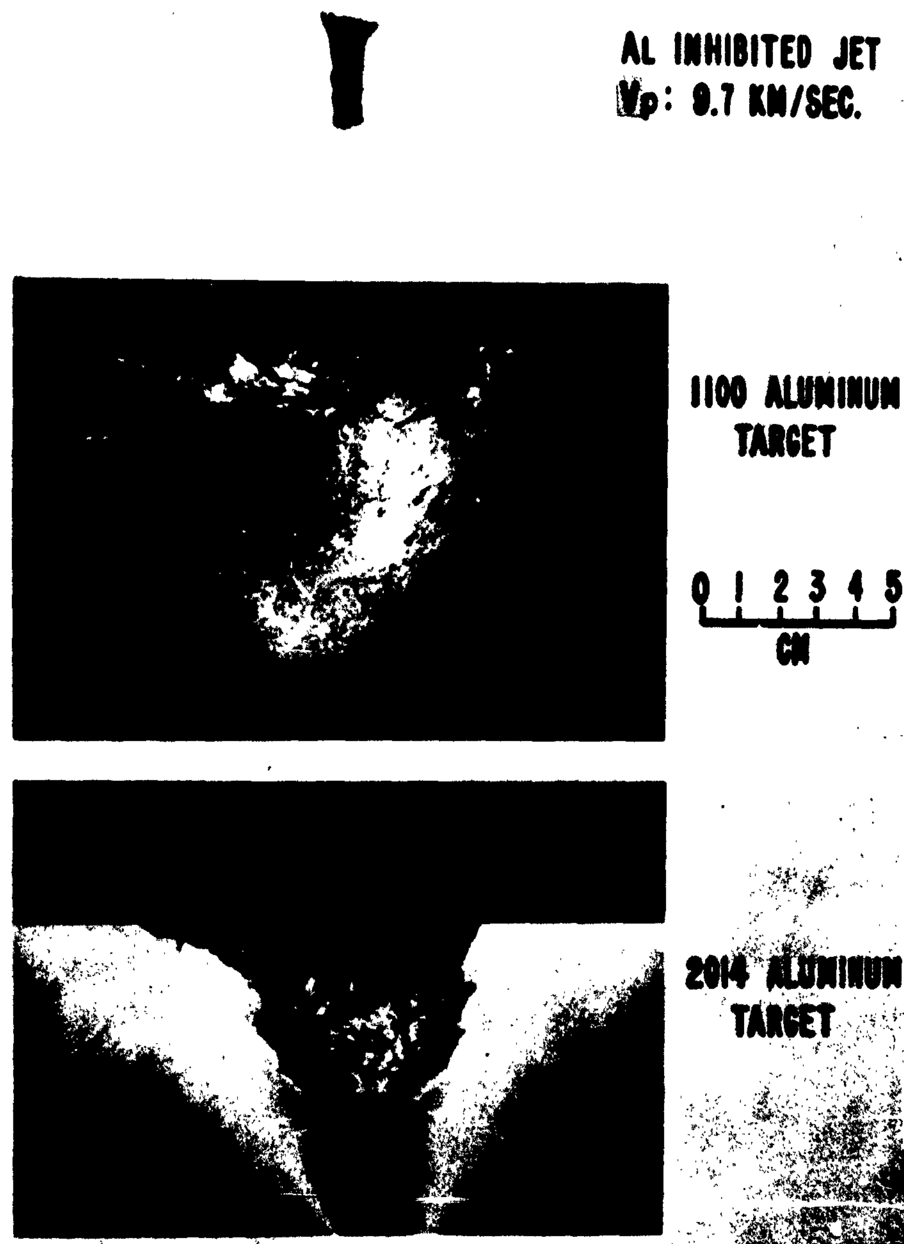
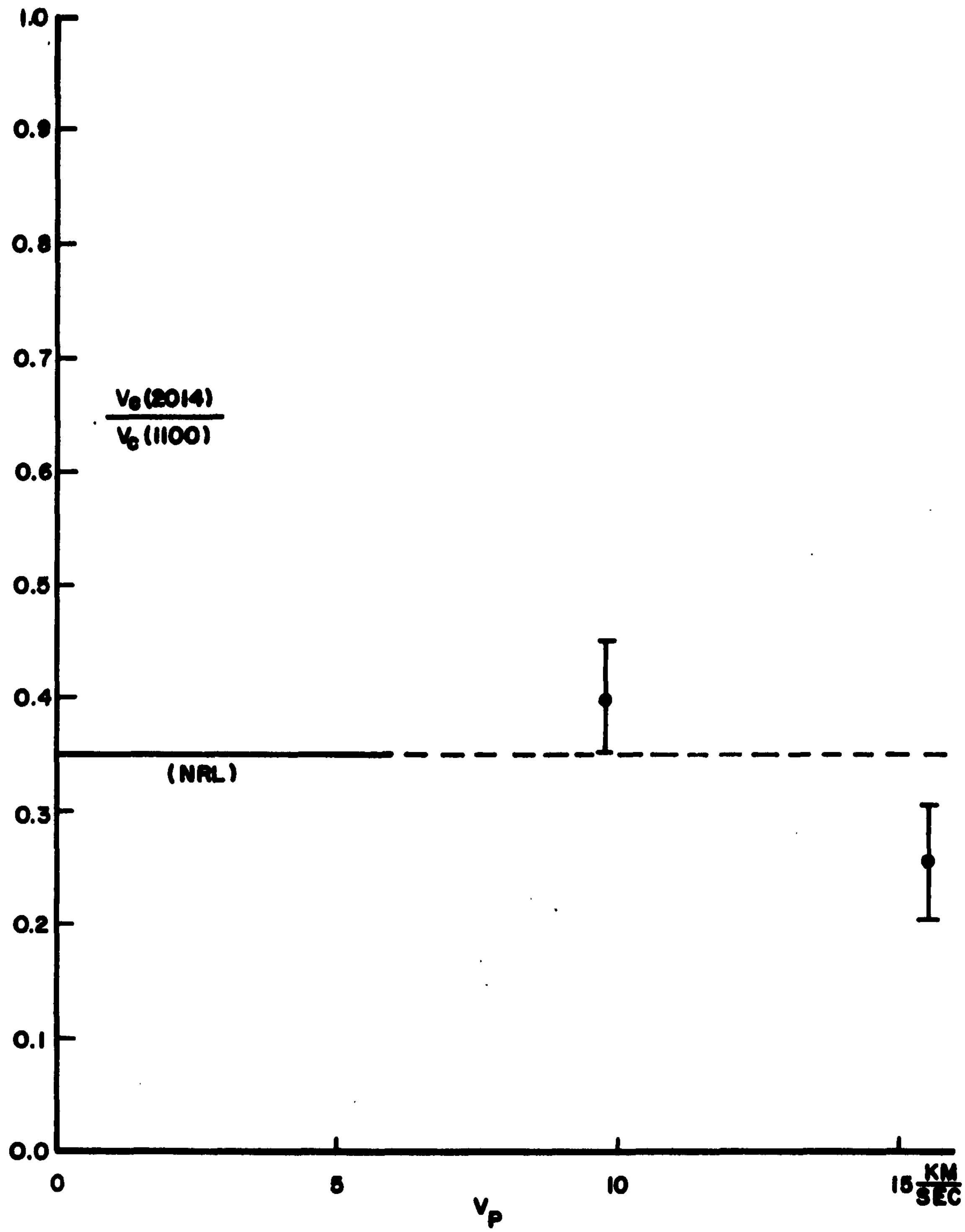
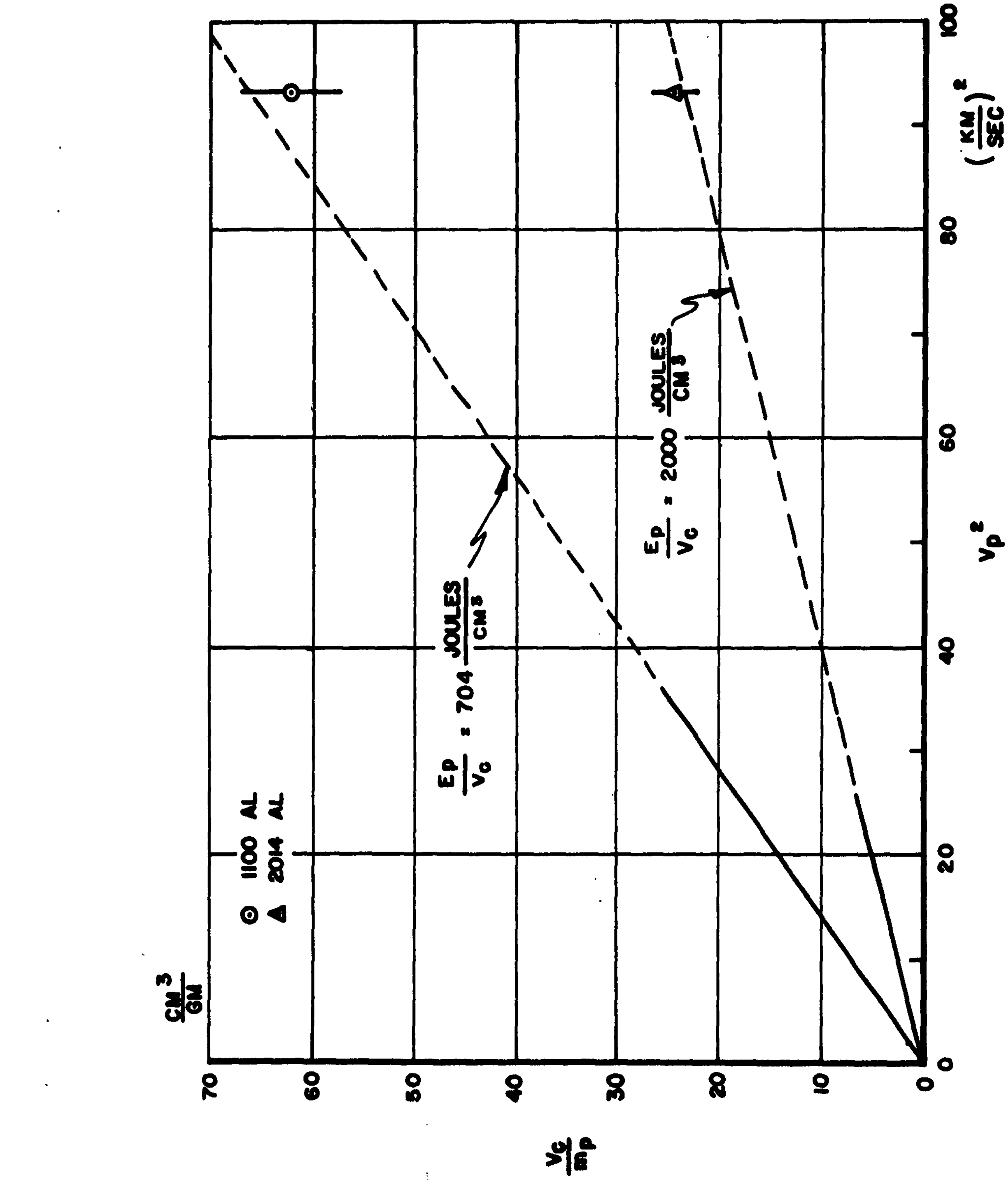

AL INHIBITED JET
Vp: 9.7 KM/SEC.
1100 ALUMINUM TARGET
0 1 2 3 4 5
CM
2014 ALUMINUM TARGET

FIG. 2



1.0
0.9
0.8
0.7
$\frac{V_e(2014)}{V_c(1100)}$
0.6
0.5
0.4
(NRL)
0.3
0.2
0.1
0.0
0
5
10
15 $\frac{KM}{SEC}$
V_P

FIG. 3



$\frac{CM^3}{GM}$
1100 AL
2014 AL
$\frac{E_p}{V_c} = 704 \frac{JOULES}{CM^3}$
$\frac{E_p}{V_c} = 2000 \frac{JOULES}{CM^3}$
$\frac{V_c}{m_p}$
V_p^2
$\left(\frac{KM}{SEC}\right)^2$
0
10
20
30
40
50
60
70
0
20
40
60
80
100

FIG. 4

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